

Systematic study of turbulence properties through reflectometry spectra

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INTRODUCTION

- Objective: Systematic study of turbulence properties from fluctuation reflectometer [1] data
- Motivation: discovery of general trend or global pattern
- Methodology: Decomposition of spectrum → parameter reduction → database

Parametrization of frequency spectra

Nonlinear curve fitting (or constrained optimization): $S_{fit} = C_{DC} + C_{LF} + C_{BB} + C_N$

- Decomposition of frequency spectrum
 - The direct current (DC) component
 - The low-frequency (LF) fluctuations
 - ↔ MHD, ZFs, ...
 - The broadband (BB) fluctuations
 - ↔ turbulence
 - The noise (N) level: constant

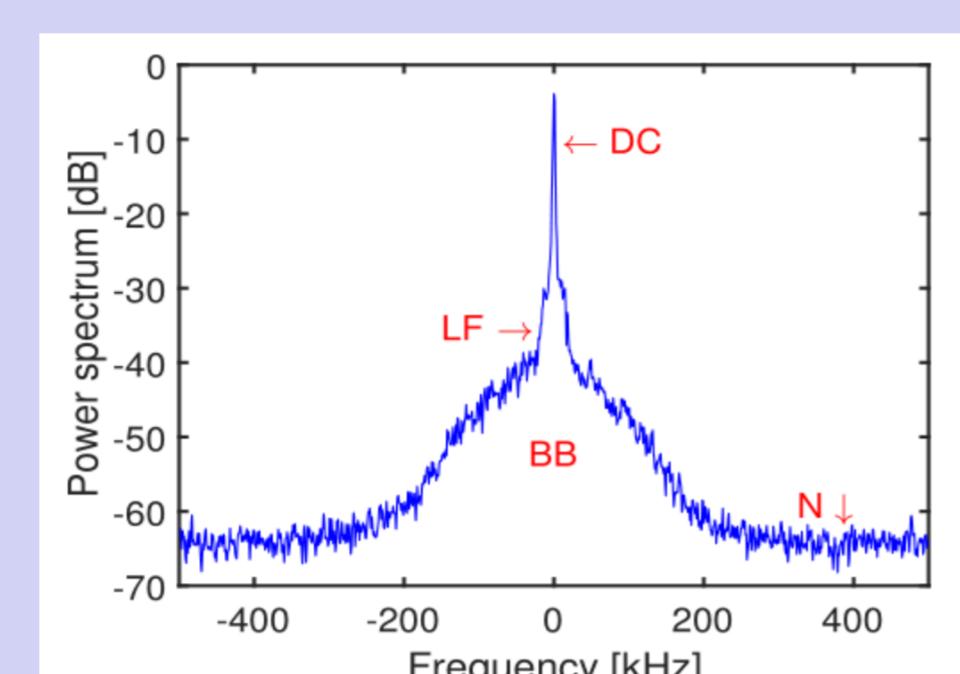


Figure 1. Typical spectrum with different components.

- Fitting functions:
 - DC & LF components: Gaussian functions
 - The BB turbulence: 2 options
 - ✓ The Generalized Gaussian (GG) function
 - $C_{BB}^{GG} = A_{BB} \exp \left[-\left(\frac{|f| - \mu_{BB}}{\sigma_{BB}} \right)^{\beta_{BB}} \right]$
 - ✓ FFT of the Taylor function [5]
 - $C_{BB}^{\text{Taylor}} = A_{BB} \times \text{FFT} \{ \exp[-\Delta_{BB}(t - \tau_{BB} + e^{-t/\tau_{BB}})] \times \exp(\mu_{BB}) \}$

• Cost function (S : normalized spectrum, S_{fit} : fitting model, $lg = 10 \times \log 10$)
 $F_{cost} = 0.5 \times \frac{|\lg(S_{fit}) - \lg(S)|^2}{A_{lg}} + 0.5 \times |S_{fit} - S|^2$,
 $A_{lg} = \int_{f_{min}}^{f_{max}} [\lg(S)]^2 df, S = S_0 / \int_{f_{min}}^{f_{max}} S_0(f) df$

- Global convergence
 ➔ multiple initial guesses

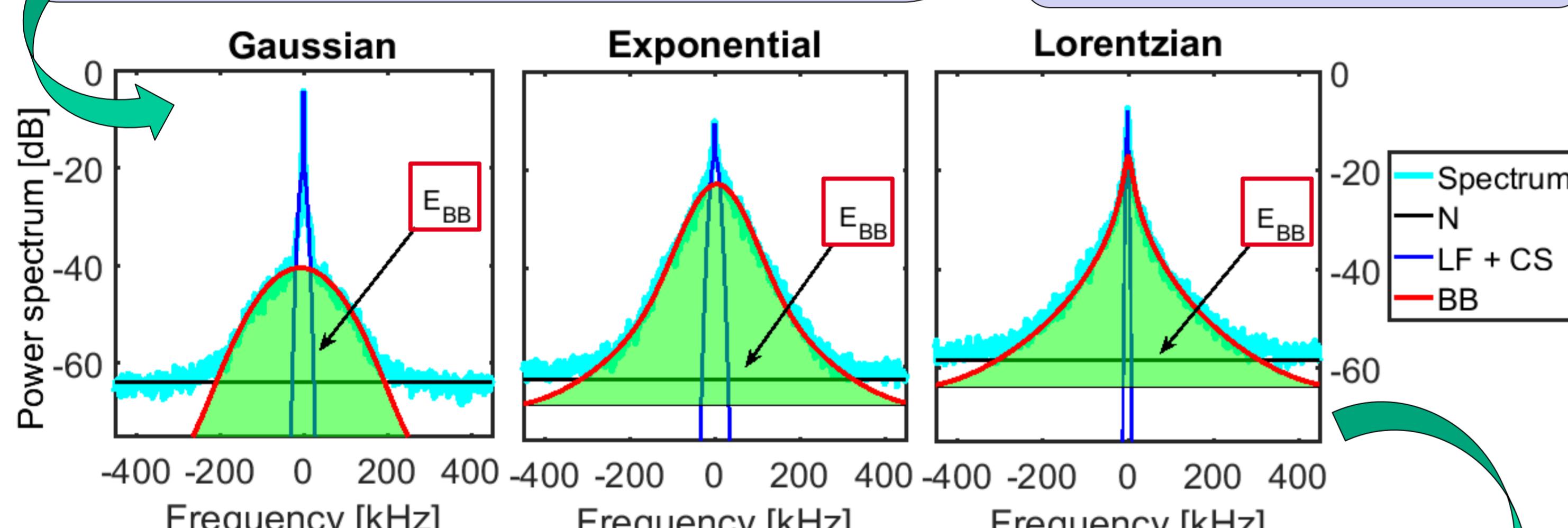


Figure 1. Typical spectra fits (Taylor function for the BB). FFT calculated over 1025 points and 50% overlap.

- Database**
- Includes 350,000 acquisitions from 6,000 Tore Supra discharges
 - Contains Ohmic, ICRH, LH, limited ECRH plasmas
 - Global (B_t, I_p, \dots), local (n_e, T_e, \dots) & diag. (F, ρ_c, \dots) parameters
 - Turbulence properties (E_{BB}, W_{BB}, \dots)

Ohmic plasmas: broadband contribution drops in the core

- Drop from $E_{BB} > 30\%$ outside $\rho_{q=1}$ to $E_{BB} < 10\%$ in the core (Fig. 2).
- The E_{BB} basin location (Fig. 2) and width (Fig. 3) linked to the $q=1$ surface.

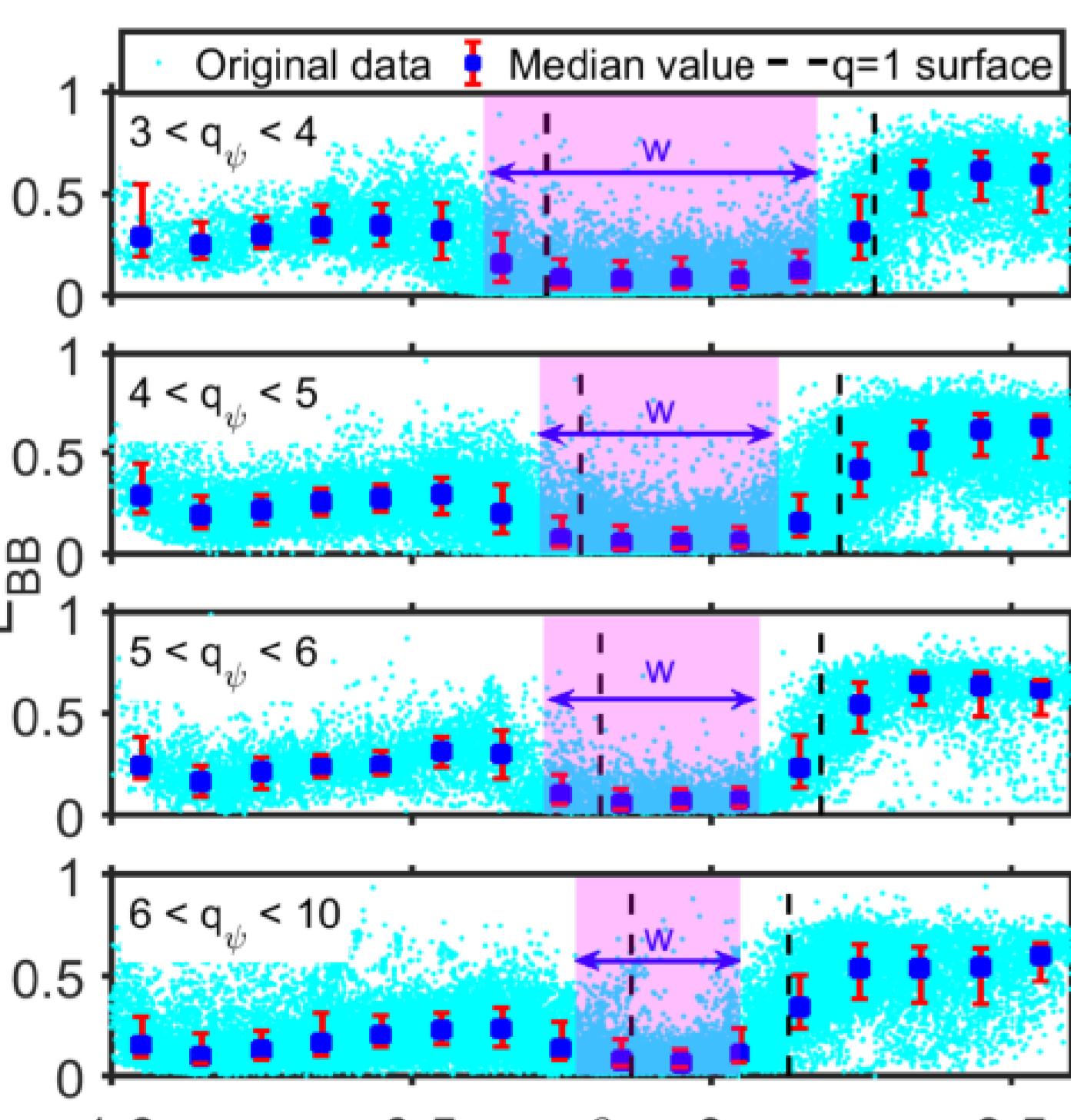


Figure 2. Radial profiles of E_{BB} for different q_ψ . The median value is calculated from a small radial interval. The BB basin is indicated by the shaded area with basin width indicated by w .

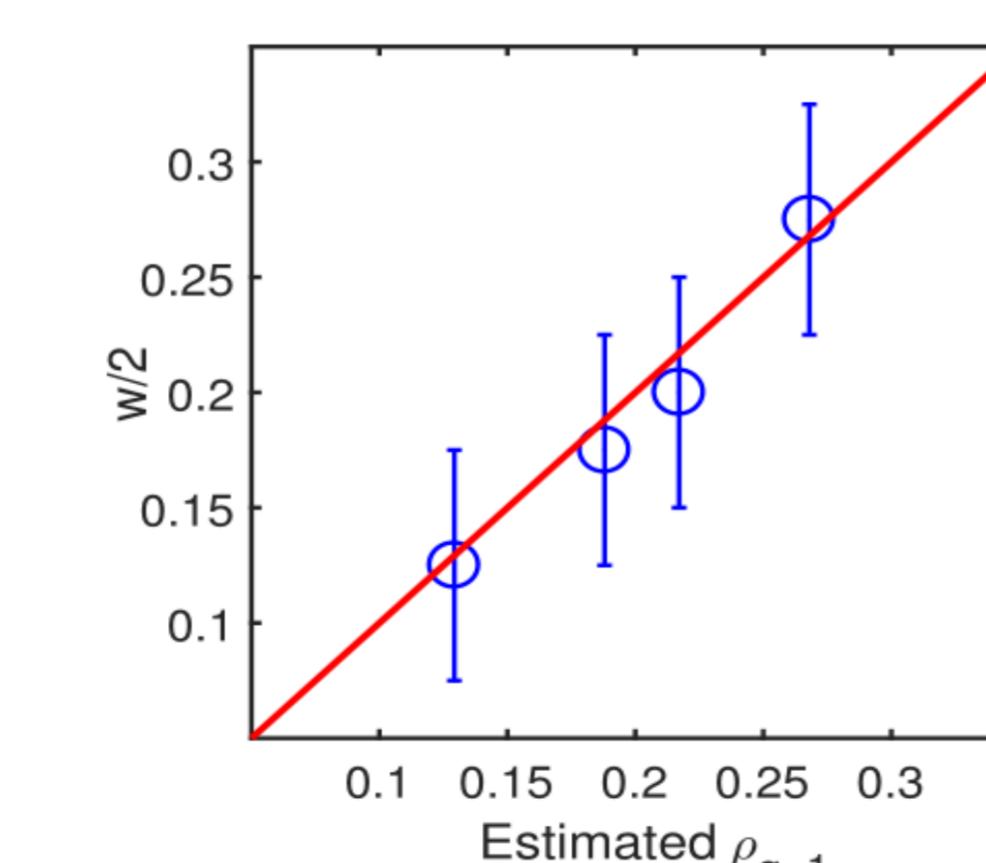


Figure 3. Half-width of E_{BB} basin vs $q=1$ position

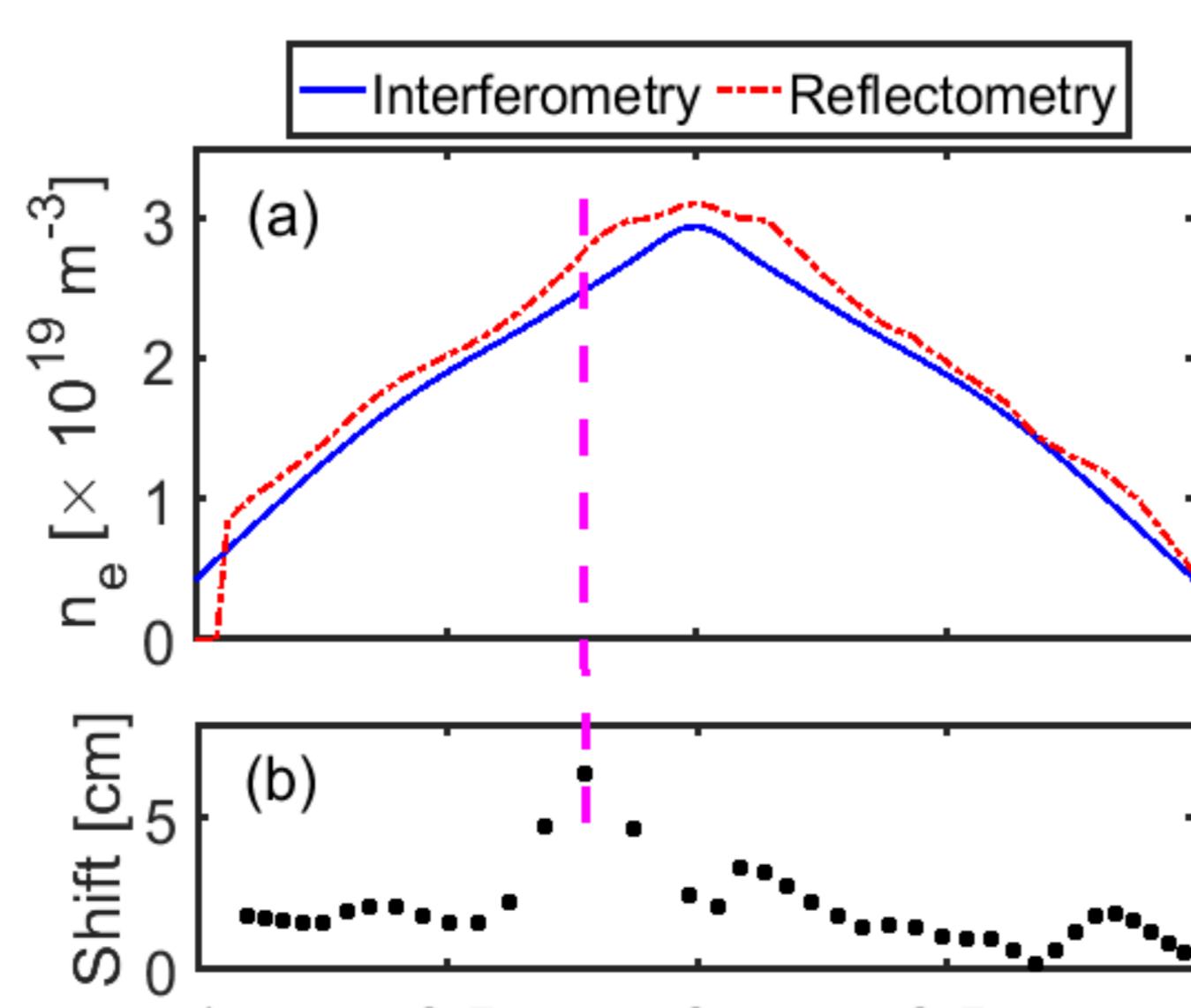


Figure 4. (a) Density profiles and (b) Difference of the cutoff positions from interferometry w.r.t. reflectometry at different radial positions.

- The systematic radial shift toward the HFS w.r.t. $\rho_{q=1}$ may be due to an underestimation of the core density profile measured by interferometry (Fig. 4).

Higher broadband contribution in SOC than LOC

- The global trend of E_{BB} remains in LOC and SOC regimes.
- In all radial positions, $E_{BB}^{\text{SOC}} > E_{BB}^{\text{LOC}}$.

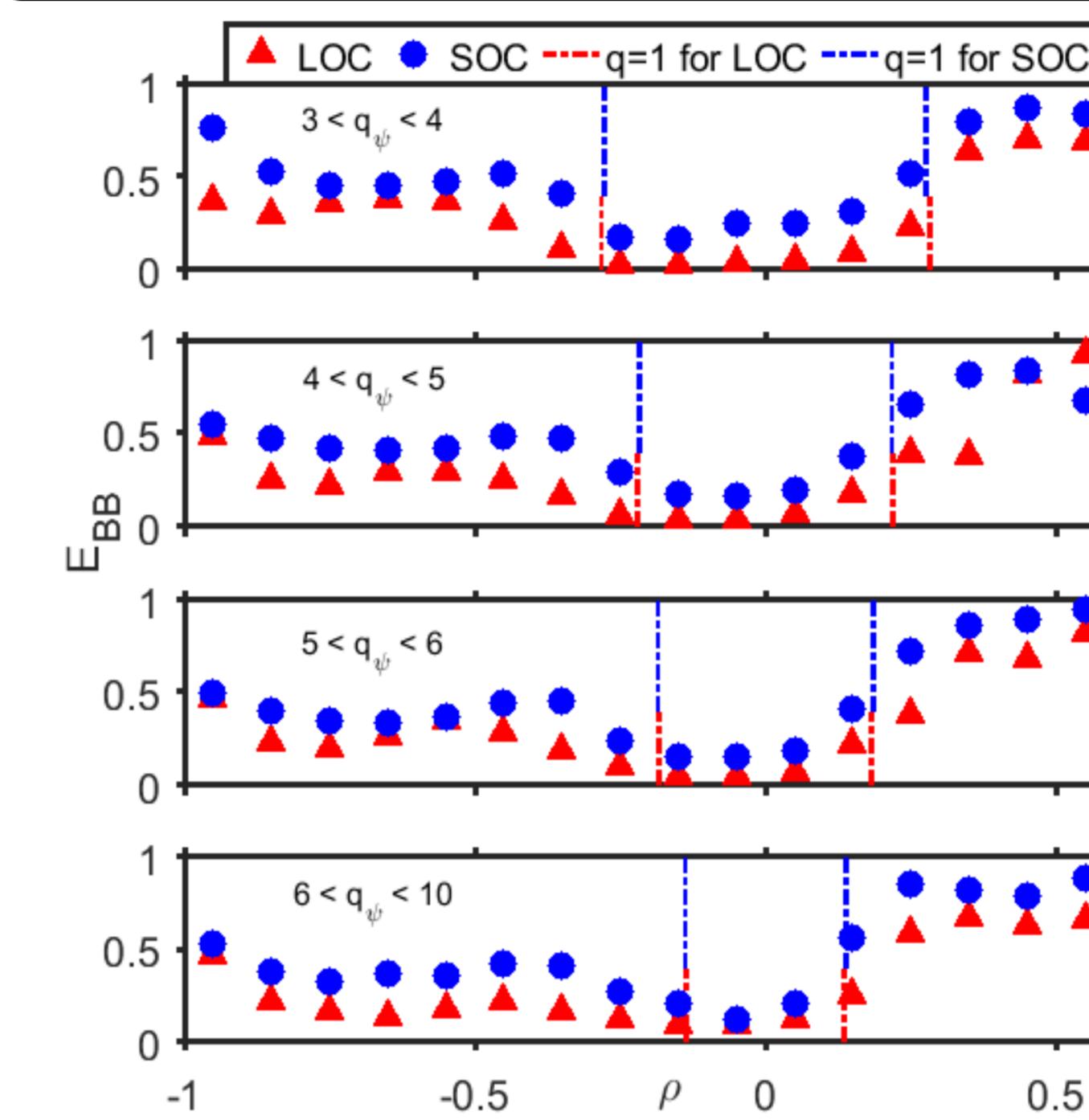


Figure 5. Radial profiles of E_{BB} for different q_ψ in LOC & SOC.

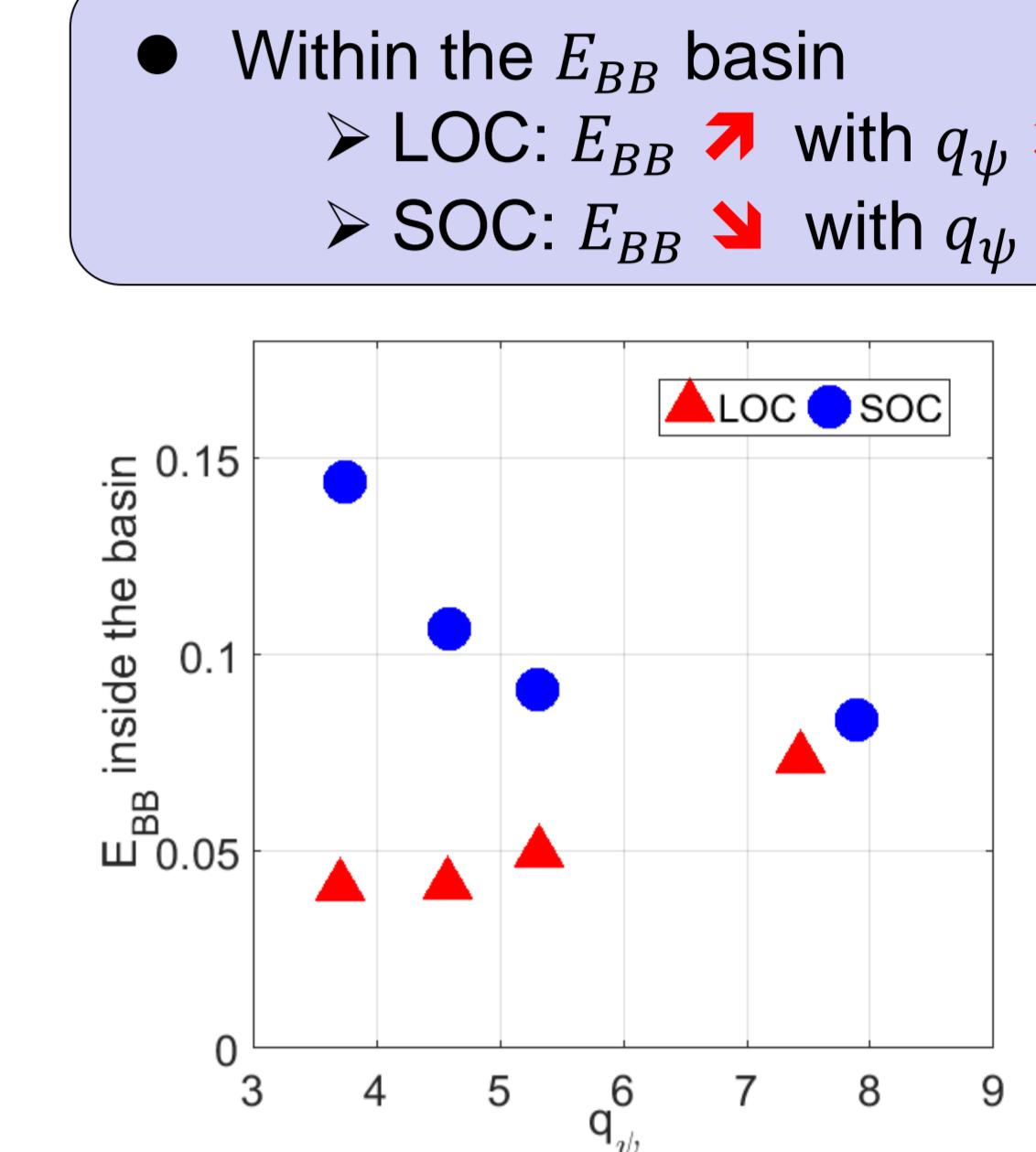


Figure 6. Evolution of E_{BB} within the E_{BB} basin w.r.t. q_ψ .

Evolution of the E_{BB} basin with increasing P_{ICRH} & P_{LH}

- Within the basin, $E_{BB} \nearrow$ with $P_{ICRH} \nearrow$ (Fig. 7a).
- The basin disappears at high P_{ICRH} (very weak basin above 2.5 MW in Fig. 7a).
- The E_{BB} basin remains even for $P_{LH} > 3$ MW (Fig. 7b).
- Large scatter of E_{BB} might be linked to the turbulence evolution during the sawtooth activity, which needs further study.

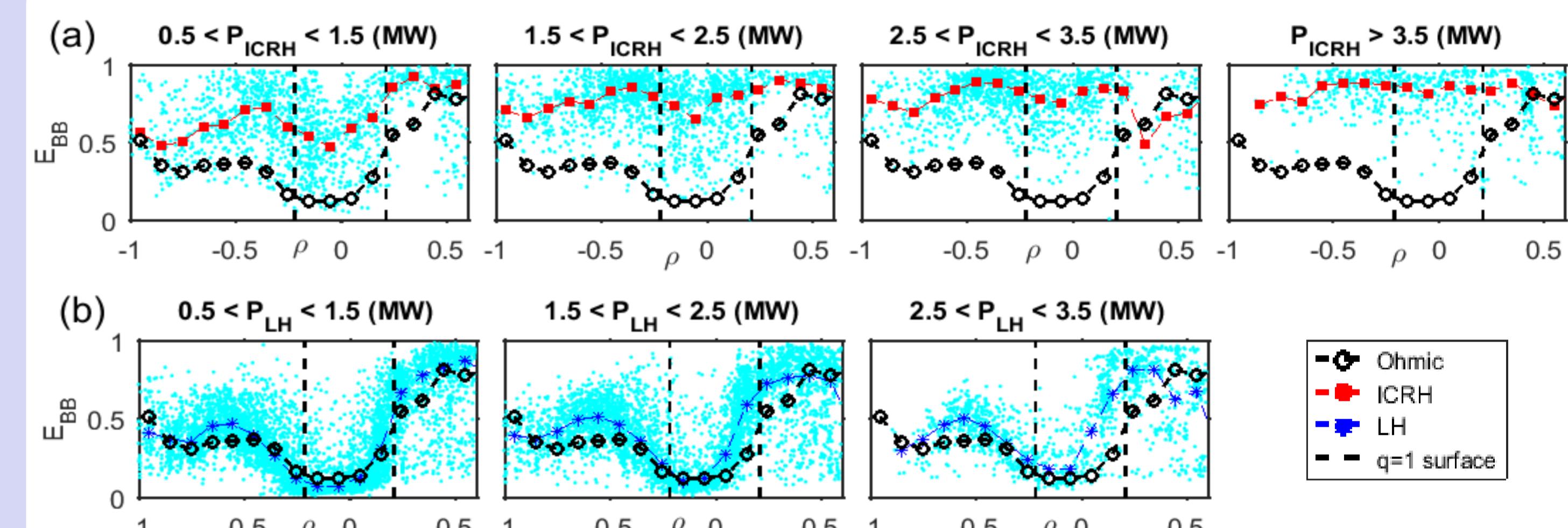


Figure 7. Radial profiles of E_{BB} with increasing ICRH and LH power under the condition $4 < q_\psi < 5$.

- The radial profiles of E_{BB} recover in a systematic study (Fig. 8) the observations as in the Ohmic, ICRH & LH dedicated shots (Fig. 9).

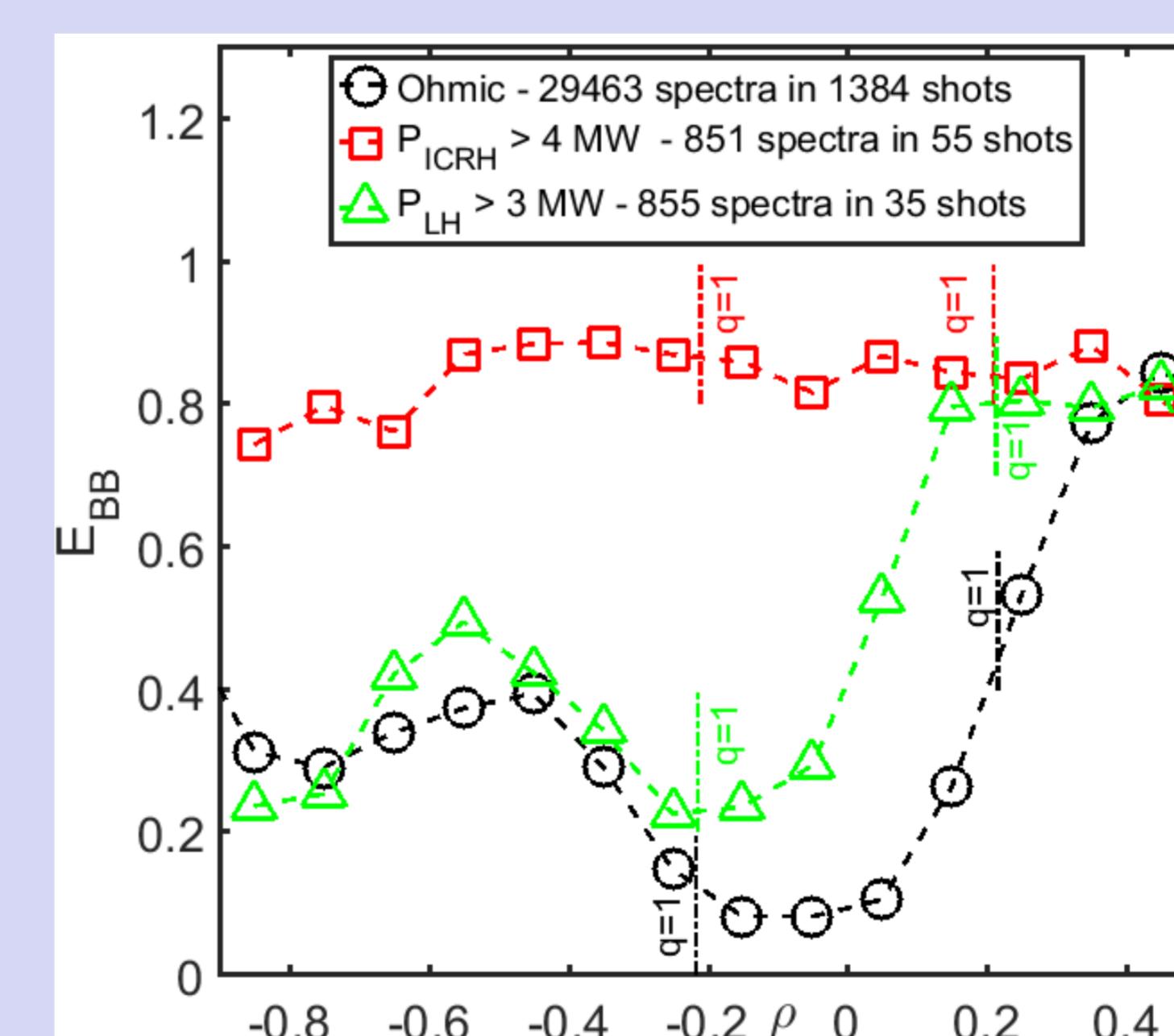


Figure 8. Radial profiles of E_{BB} in Ohmic, ICRH and LH plasmas.

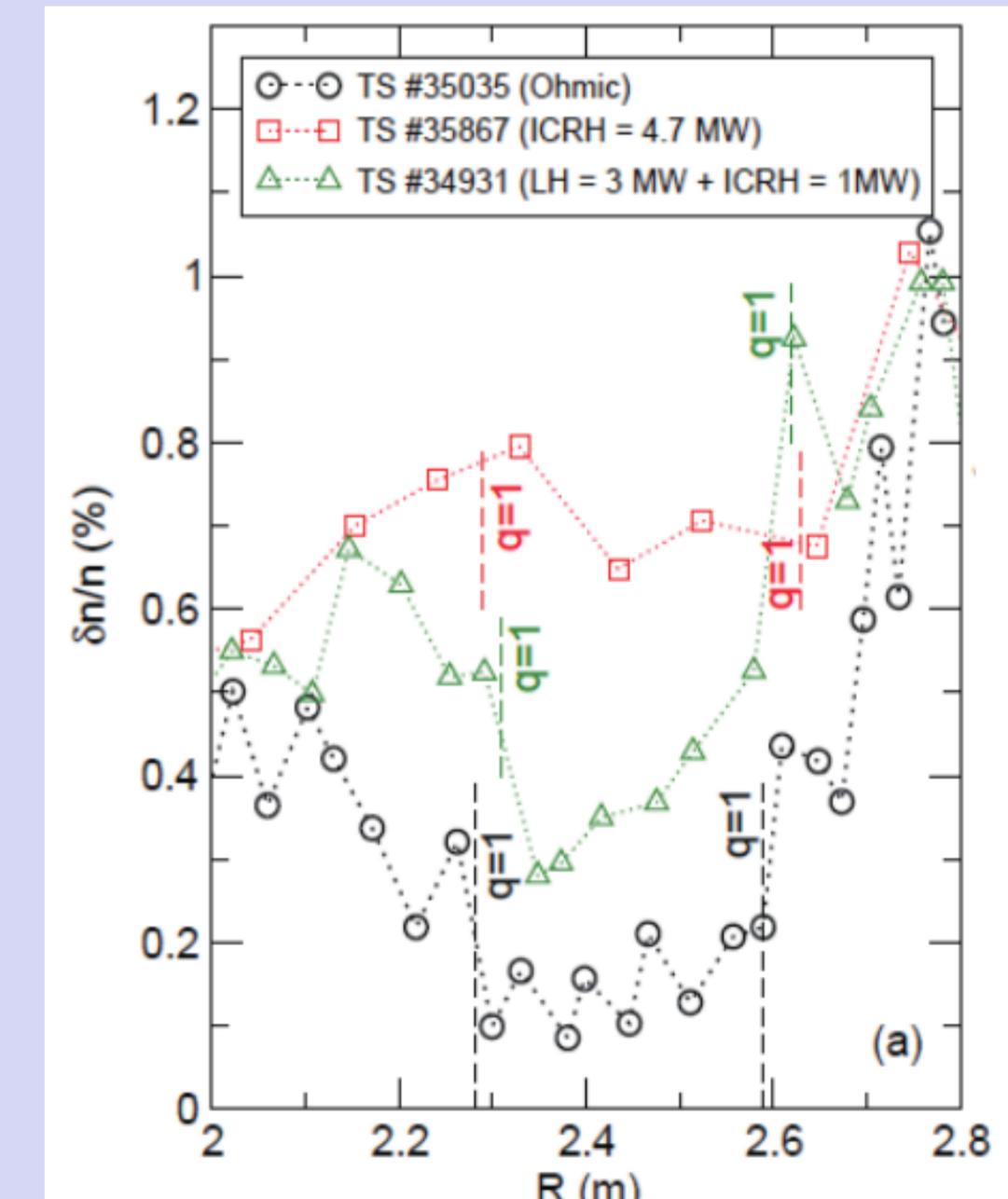


Figure 9. Fluctuation level calculated from typical discharges. In Ohmic, ICRH and LH plasmas. Reprinted from [6].

- The evaluation of $\delta n/n$ from the decomposition components is underway.

CONCLUSION

- ❖ The broadband contribution (E_{BB}) from the decomposition of turbulence spectrum drops in the core and its location and width are linked to the $q=1$ surface in Tore Supra database.
- ❖ In Ohmic plasmas, E_{BB} is higher in SOC regime than in LOC regime.
- ❖ Inside the basin, E_{BB} trend w.r.t. q_ψ is opposite for LOC (\nearrow) and SOC (\searrow).
- ❖ The E_{BB} increases much faster with P_{ICRH} than with P_{LH} .
- ❖ The basin disappears for moderate P_{ICRH} while it remains at higher P_{LH} .

References

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